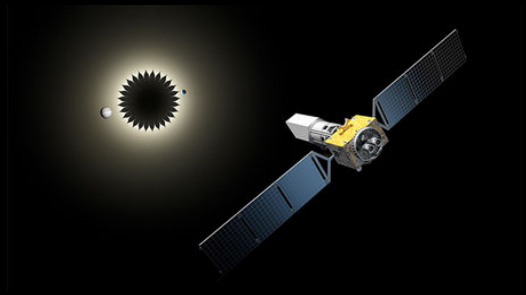
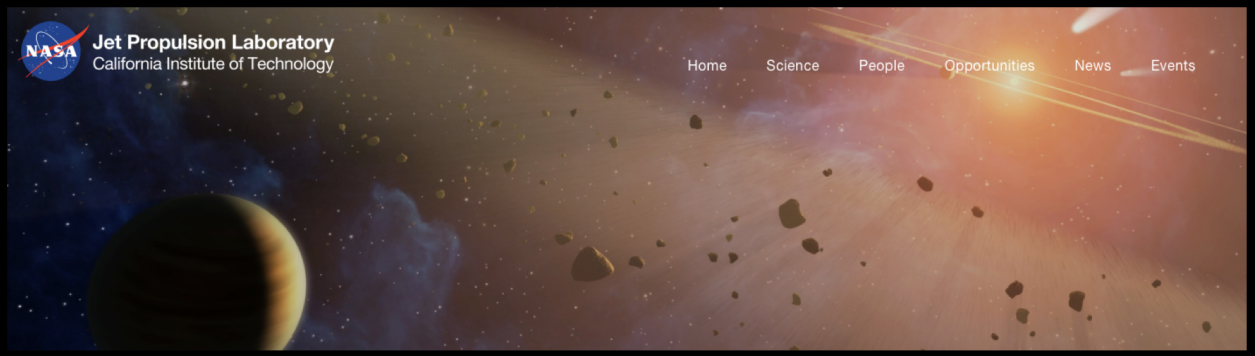
SISTER: Imaging Exoplanets with Starshade

Sergi R. Hildebrandt

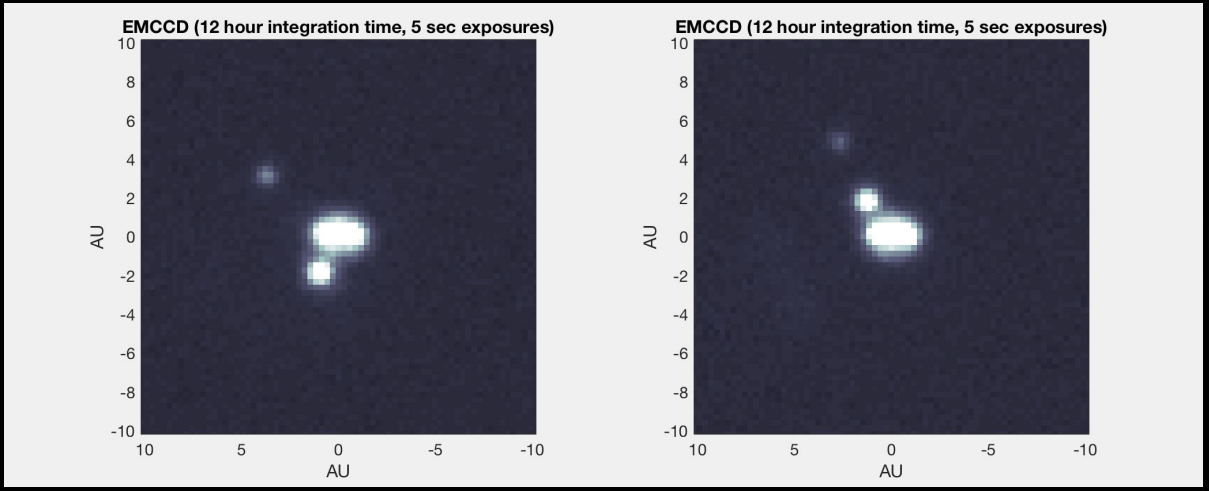


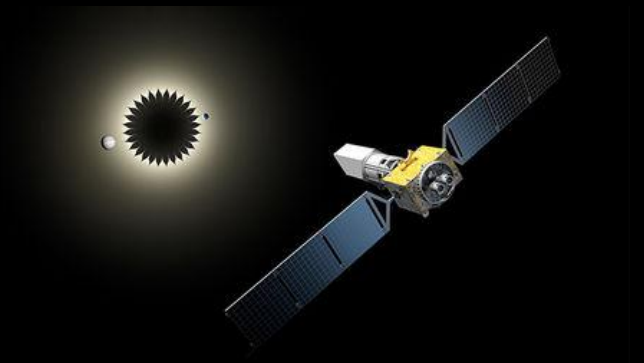
Exoplanetary Science Initiative 03/25/19



Epochs with the starshade

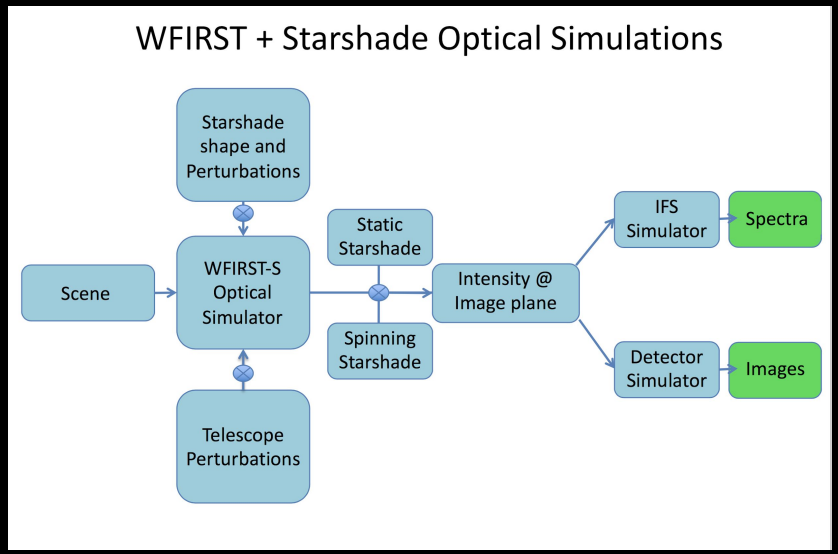
The last two epochs in the set of images (T=3, and 4 years) correspond to simulations of observations of WFIRST with an starshade.





Epochs with the starshade

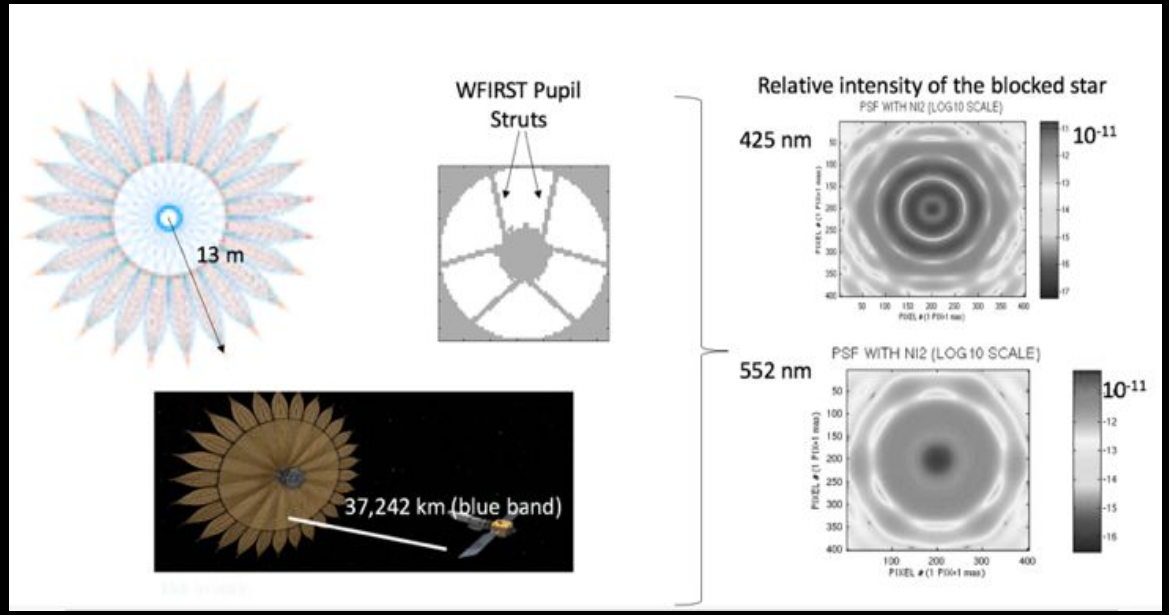
SISTER(*) allows one to easily generate simulations of what a telescope with a starshade, SS, will be able to image. SISTER comes with a detailed practical documentation and the software is open source (public release date 04/11/19, contact Sergi[1] if interested).



Starshade Imaging Simulation Toolkit for Exoplanet Reconnaissance: S.R. Hildebrandt[1] (srh@caltech.edu), S.B. Shaklan[1], E.J. Cady[1], and M.C. Turnbull[2,1]. (1) Jet Propulsion Laboratory & California Institute of Technology Pasadena, California (2) SETI Institute, Carl Sagan Center for Life in the Universe

Epochs with the starshade

WFIRST (main mirror 2.4 m): proposed rendezvous mission



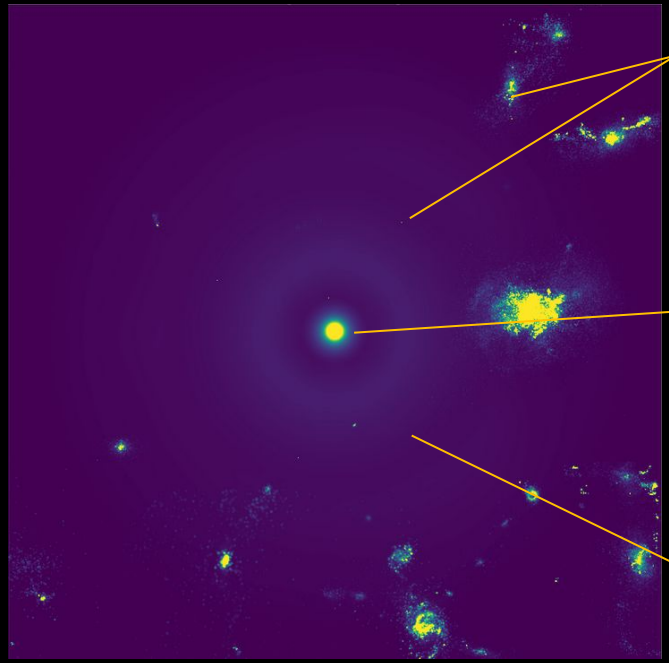
- PSF is derived for an array of wavelengths
- PSF is derived at different locations from the center of the SS on the image plane

PSF basis depends on *wavelength* and relative *position* with respect to the SS

Epochs with the starshade

Example: solar System[1] at 10 pc (face on)

33’’



Background galaxies and other galactic stars

Sun: planets within few arcsec remain invisible below its halo

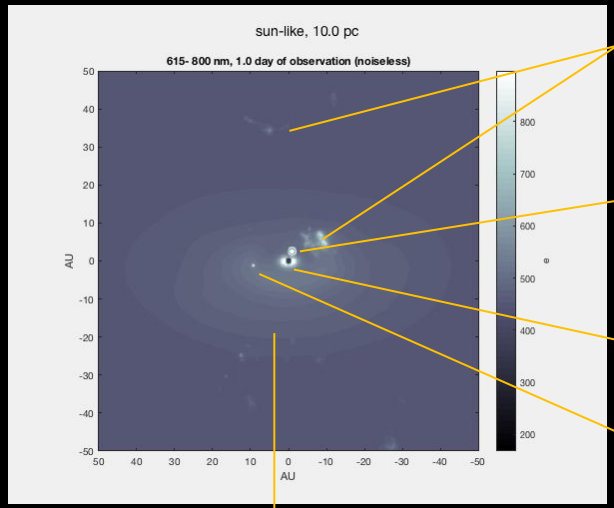
Exozodiacal light

[1]Astrophysical input data from The Haystacks Project: https://asd.gsfc.nasa.gov/projects/haystacks/haystacks.html

Epochs with the starshade

Example: solar System[1] at 10 pc with WFIRST (60° inclination. Processed with SISTER)

5’’

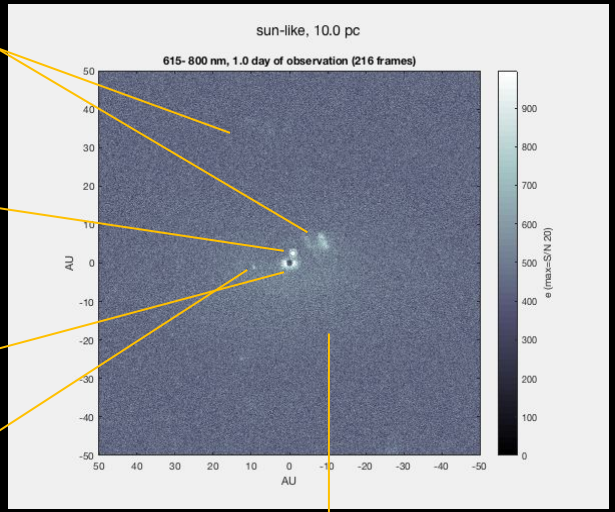


Background objects

Jupiter

Blocked Star

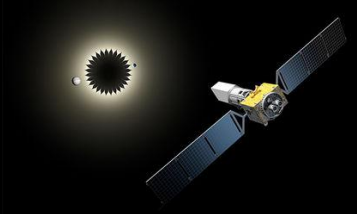
Saturn



Exo-zodiacal light (with forward scattering)

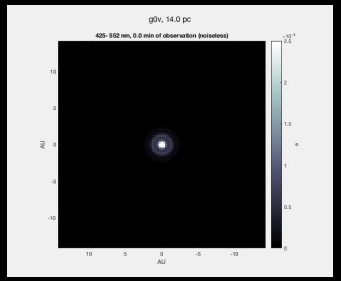
Noise: read noise, dark current, shot noise

Epochs with the starshade



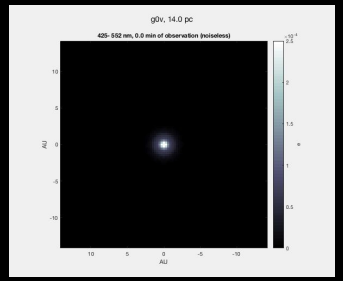
The WFIRST Exoplanet Imaging Data Challenge sims steps by step

47 Uma star blocked by the SS (G0V, 14pc, V5)



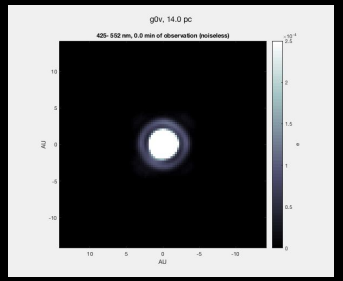
Contrast[1]: 8 10^{-11}

+ Telescope pointing jitter (20 mas)



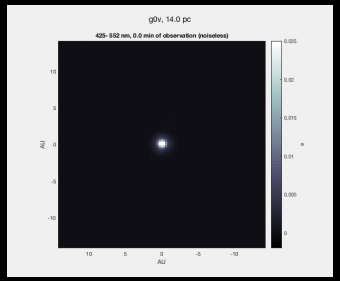
Contrast: 8 10^{-11}

+ Non-ideal SS (maximum distortion within specs)



Contrast: 5 10^{-9}

Same as before stretch / 100

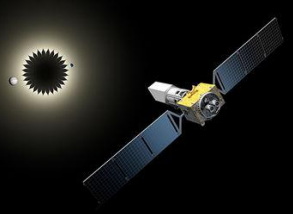


Contrast: 5 10^{-9}

2’’

Contrast is defined here as the ratio between the total counts of the image shown and the total counts of the telescope PSF. under the same configuration. If the PSF core were to be used (half energy), multiply the contrast by 2.

Epochs with the starshade



The WFIRST Exoplanet Imaging Data Challenge sims steps by step

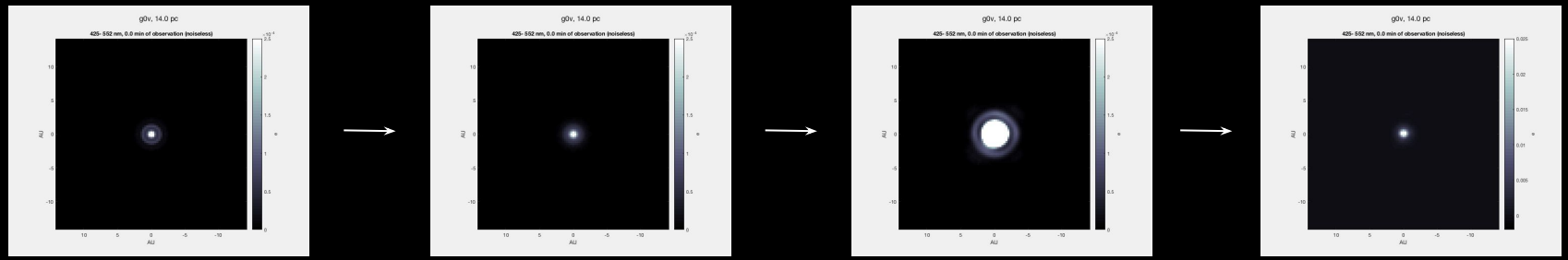
47 Uma star blocked by the SS (G0V, 14pc, V5)

+ Telescope pointing jitter (20 mas)

+ Non-ideal SS (maximum distortion within specs)

Same as before stretch / 100

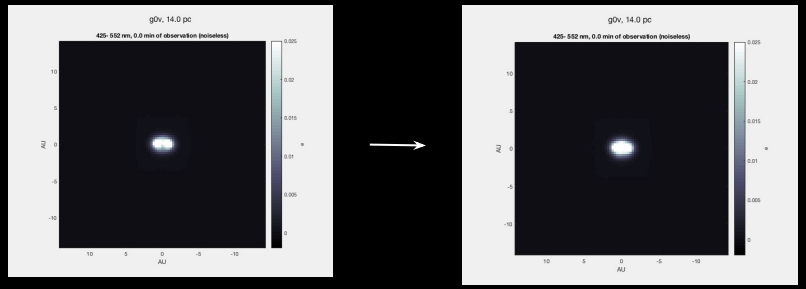
2’’



Contrast: 5 10^{-9}

Solar glint and jitter (no starlight)

All: non-ideal SS, solar glint, and jitter



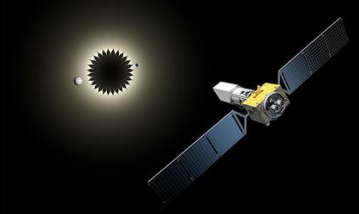
Contrast: 2 10^{-8}

Contrast: 2.5 10^{-8}

This pattern is expected to be measured well during the mission.

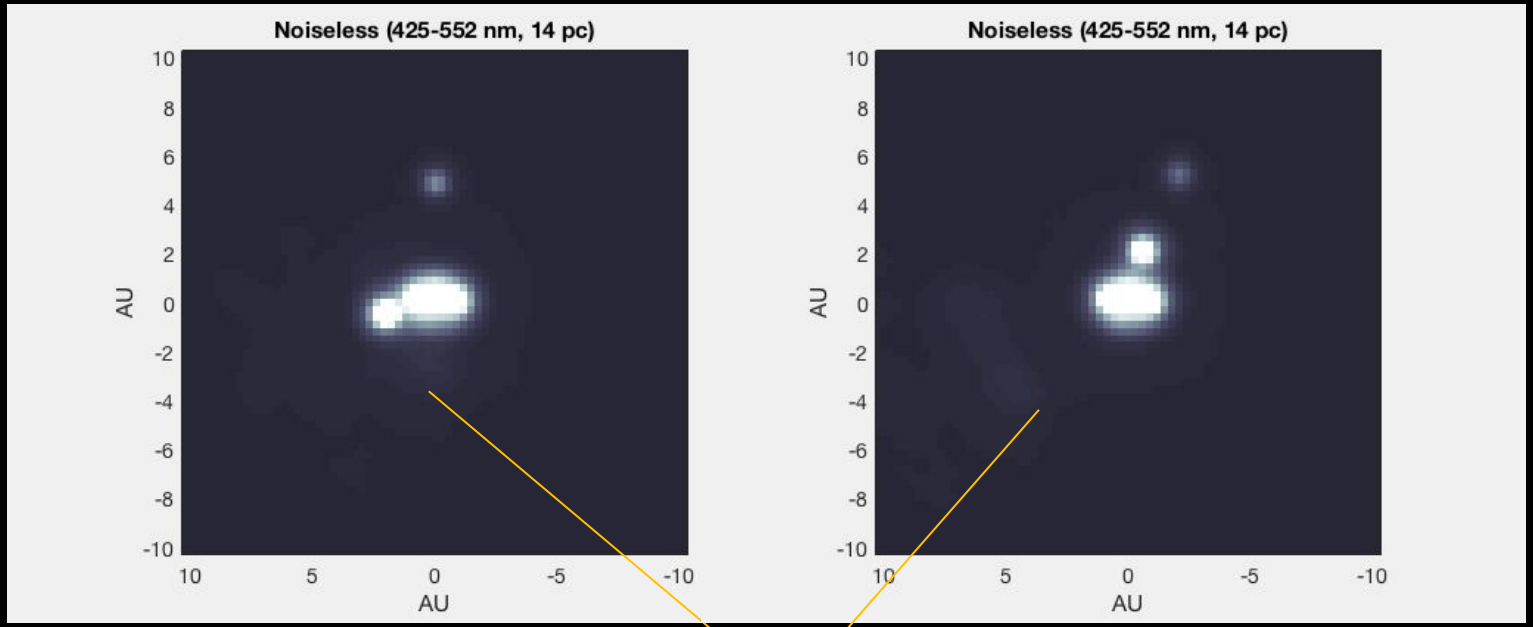
Next … adding planets and background field ...

Epochs with the starshade



Non-ideal SS, solar glint, telescope pointing jitter, background field and 2 epochs: *different* orbital parameters than the challenge.

1.5”

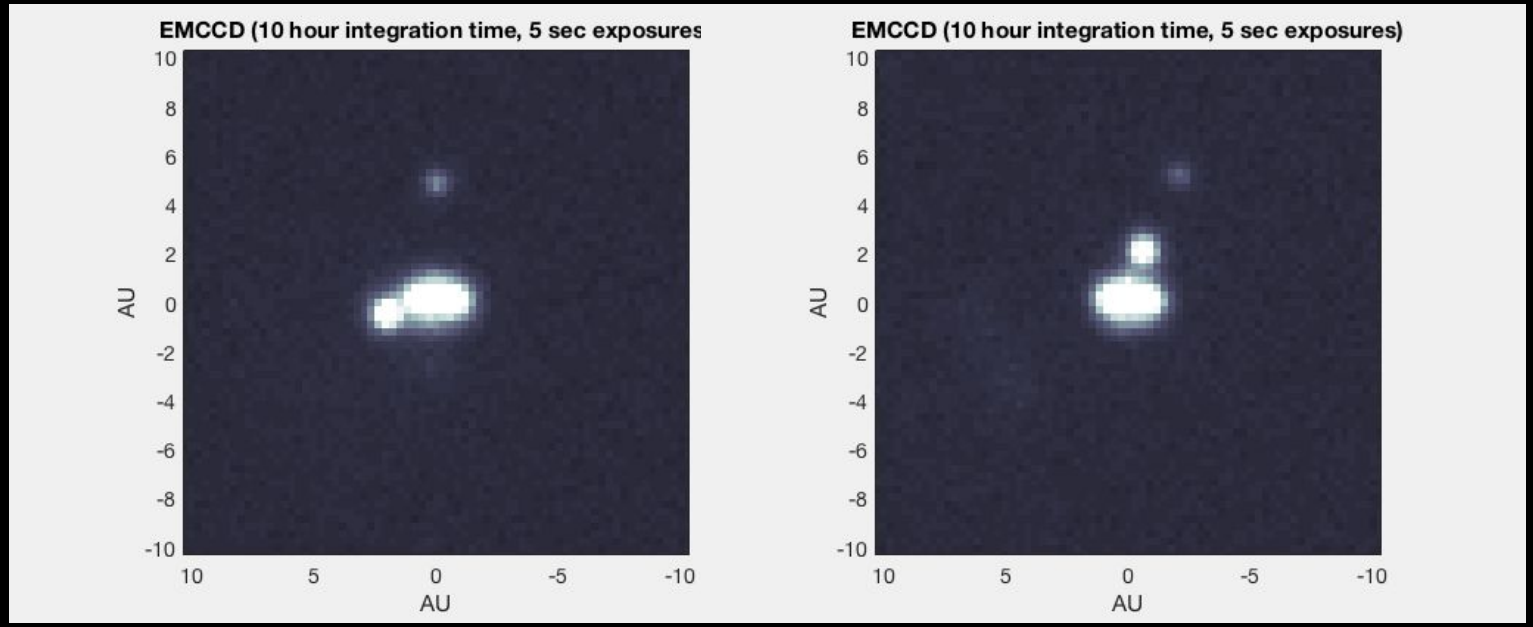


Extragalactic background is faint, but visible in these noiseless images. It moves from epoch to epoch due to the proper motion and parallax of 47 UMa.

Epochs with the starshade

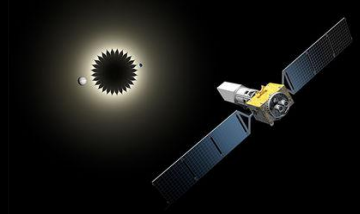
The previous noiseless images are then observed through a simulator of an EMCCD[1] detector: *different* orbital parameters, and total integration time than the challenge.

1.5”



[1]EMCCD detector model software by P. Morryssey (JPL/Caltech)

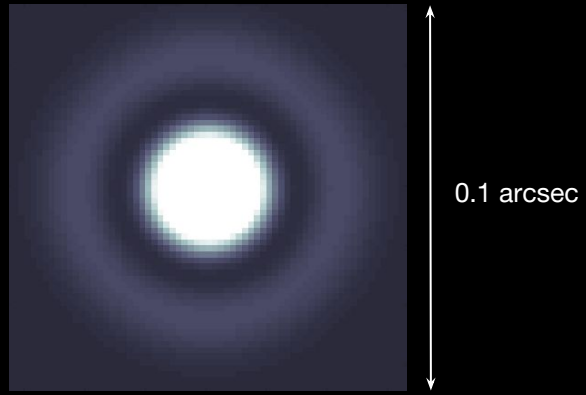
Epochs with the starshade



Both effects, residual starlight and solar glint, can be measured during the mission and can thus be subtracted well below the noise level on the images.

We provide *two files*: one with the starlight, and another one with the solar glint that would be measured after a 24 hour exposure. If either file or both are used to improve the fit of the planets, the subtraction will leave the shot noise contribution due to the starlight and solar glint in the single epoch images.

Finally, we also provide the effective PSF response of WFIRST* that is valid for the planet positions on these simulations in the band 425-552 nm. It is provided for a pixel scale of 3 mas.



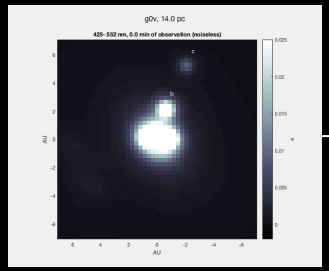
For this data challenge, we did not include the small effect of the struts, and used a circular pupil with a secondary blocking an equivalent area than in WFIRST.

Epochs with the starshade

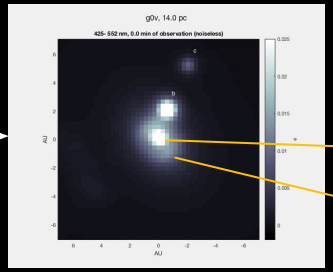
In the next round of the data challenge, we will add some more complexity to the astrophysical scene, including exozodiacal light. As an example, we show below a simulation with dust emission resembling the solar system distribution, but with 5 times its intensity.

All: non-ideal SS, solar glint, jitter, and 5x zodi

1''



Without solar glint



Starlight (non-ideal petals)

Exo-zodiacal light

The PSF file that we provide is not accurate for any emission that is partially shaded by the SS. In that case, non-linear effects of the starshade are noticeable, and a spatially dependent PSF needs be used. For the current Data Challenge, the single PSF that we provide is sufficient.

The following figure shows the average transmission curve for the SS of WFIRST in the visible band of the challenge: 425-552 nm.